(12) LEVEL II

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ADA085870

DEPARTMENT OF THE NAVY
DTNSRDC

THE POWER-AUGMENTED-RAM LANDING CRAFT CONCEPT

by

Fred H. Krause

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AVIATION AND SURFACE EFFECTS DEPARTMENT

DTNSRDC/ASED-80/03

March 1980

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IN REPLY REFER TO:
1603:FHK
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From: Commander, David W. Taylor Naval Ship R&D Center
To: Distribution List

Subj: DTNSRDC Report ASED-80/03; forwarding of

Encl: (1) DTNSRDC Report ASED-80/03, "The Power-Augmented-Ram Landing Craft Concept," by Fred H. Krause, March 1980

1. Enclosure (1) summarizes the early analytic studies and tow tank model investigations of the Power-Augmented Ram Landing Craft (PARLC) concept.

2. Subsequent studies have shown the preliminary full scale weight estimate given in enclosure (1) to be quite optimistic by conservative marine architecture standards. However, even conservative weight estimates appear compatible with high speed transport of a two-main-battle-tank payload from an LPD, LSD, or LST at standoff distances of 100 miles.

3. The report covers work performed during the period Dec 1978 through Sept 1979 under sponsorship of the Marine Corps Surface Mobility Program (E. O'Neill, DTNSRDC Code 1120, Manager).

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

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14

1. REPORT NUMBER: DTNSRDC/ASED-80/03

2. GOVT ACCESSION NO.: AD-A085870

3. RECIPIENT'S CATALOG NUMBER:

6

4. TITLE (and Subtitle): THE POWER-AUGMENTED-RAM LANDING CRAFT CONCEPT

9

5. TYPE OF REPORT & PERIOD COVERED: Summary Report, FY-79

6. PERFORMING ORG. REPORT NUMBER:

10

7. AUTHOR(s): Fred H. Krause

8. CONTRACT OR GRANT NUMBER(s):

17

9. PERFORMING ORGANIZATION NAME AND ADDRESS:
David W. Taylor Naval Ship R&D Center
Aviation and Surface Effects Department
Bethesda, MD 20084

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS:
Program Element 62543N
Task Area ZF 43 411 210
Work Unit 1-1120-021

11. CONTROLLING OFFICE NAME AND ADDRESS:
David W. Taylor Naval Ship R&D Center
Marine Corps Program Office (1120)
Bethesda, MD 20084

11

12. REPORT DATE: Marc[redacted]80

13. NUMBER OF PAGES: 39

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office):

15. SECURITY CLASS. (of this report): UNCLASSIFIED

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE:

16. DISTRIBUTION STATEMENT (of this Report)

APPROVED FOR PUBLIC RELEASE: DISTRIBUTION UNLIMITED

16 F43411

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

12 41

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)
Power-Augmented-Ram
Landing Craft
Surface Effect Ship
Tow Tank Investigation
Radio-Controlled Testcraft

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The Power-Augmented-Ram Landing Craft (PARLC) concept, combining surface effect ship and power-augmented-ram technology into one vehicle, was formulated in early FY-79. This report summarizes the analytical studies and model tests of the PARLC to date. These investigations show the PARLC is capable of transiting a 100-nm distance from ship to shore at speeds in excess of 90 knots while carrying a 240,000-lb payload.

DD FORM 1473, 1 JAN 73 EDITION OF 1 NOV 65 IS OBSOLETE
S/N 0102-014-6601

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

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TABLE OF CONTENTS

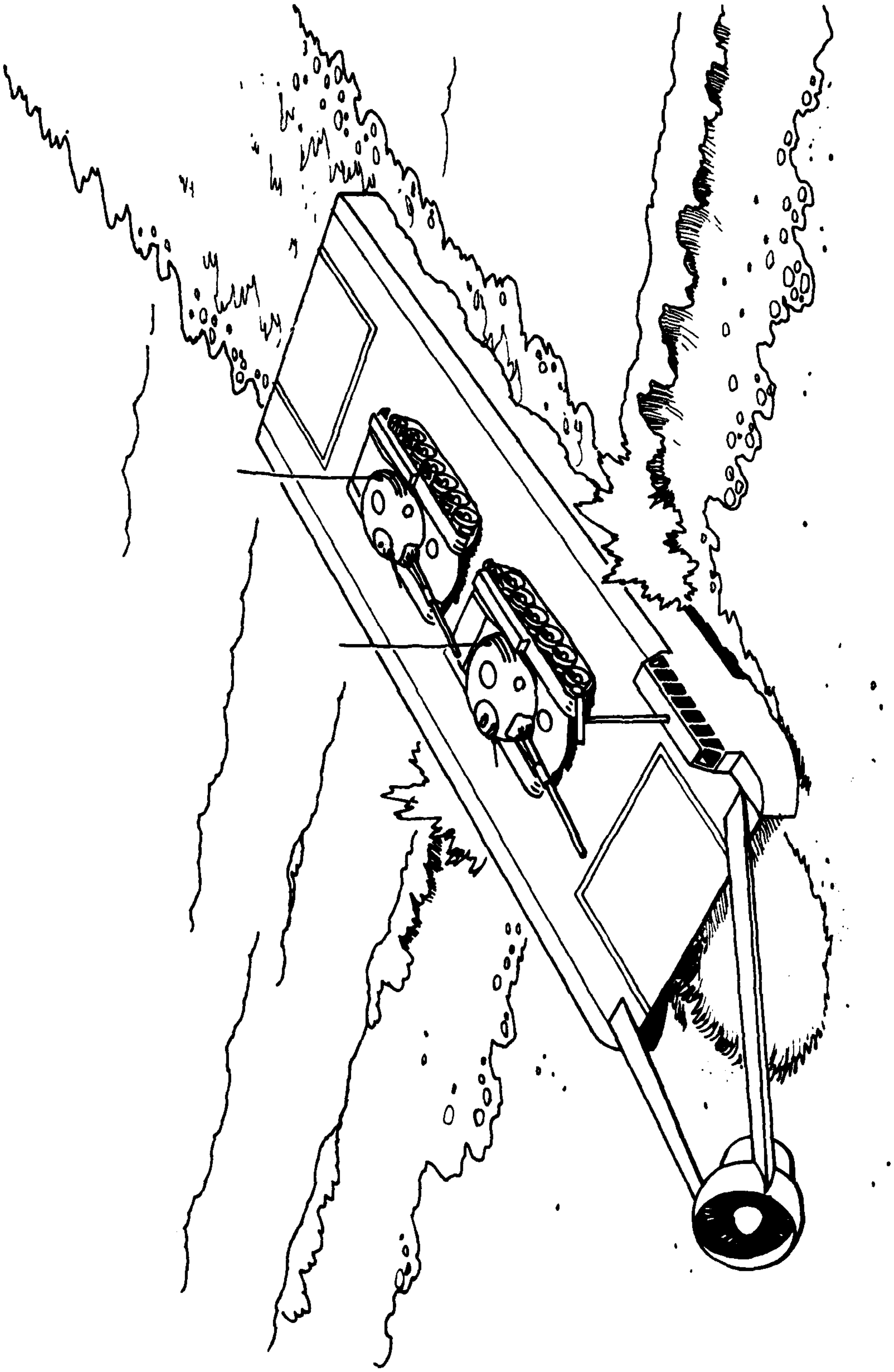
LIST OF FIGURES

Page

LIST OF TABLES

NOTATION

cg	Center of gravity
D	Drag
D_{min}	Minimum drag
$H_{1/3}$	Significant wave height - average height of the one-third highest waves
SS	Sea state
Vel	Velocity
f	Flap angle
Θ	Pitch angle
Θ_f	Propulsor angle



Power Augmented Ram Landing Craft

ABSTRACT

The Power-Augmented-Ram Landing Craft (PARLC) concept, combining surface effect ship and power-augmented-ram technology into one vehicle, was formulated in early FY-79. This report summarizes the analytical studies and model tests of the PARLC to date. These investigations show the PARLC to be an attractive surface mobility concept. The PARLC is capable of transiting a 100-nm distance from ship to shore at speeds in excess of 90 knots while carrying a 240,000-lb payload.

ADMINISTRATIVE INFORMATION

This investigation was conducted by the New Vehicle Office (Code 1603) of the Aviation and Surface Effects Department at the David W. Taylor Naval Ship Research and Development Center (DTNSRDC), and was sponsored by the Marine Corps Surface Mobility Exploratory Development Program (Code 112). The project was funded by the Naval Material Command under Program Element 62543N, Task Area ZF 43-411-210, and Work Unit 1-1120-021.

INTRODUCTION

The Power-Augmented-Ram Landing Craft (PARLC) design study was initiated during the first quarter of 1979. The resultant initial design is shown in the frontispiece. The vehicle flies on a cushion of air provided by the forward mounted propulsor--the only source of power installed on the craft. The exhaust from this engine is directed under the deck and is partially stagnated between the flap, sidehulls, and the water surface, generating a static lift of up to 10 times the installed thrust while still recovering 70 percent of the installed thrust for acceleration. This phenomenon is called power-augmented-ram (PAR).

The power-augmented-ram technology base and the surface effect ship (SES) technology base form the foundation on which the PARLC is built. The concept borrows lift and propulsion technology from the PAR data base, including propulsor location, propulsor angle, power required for take-off, and excess thrust available for cruise. The SES data base provides estimates of drag at forward speed, lateral stability characteristics, and sidehull designs. This report summarizes the design and performance of the first PARLC.

CONFIGURATION DESCRIPTION

A three-view of the full-size craft is shown in Figure 1. The PARLC is 90 ft (27.4 m) in overall length and 35 ft (10.7 m) in overall beam, with a small pilot house located forward over the port endplate. The endplates extend 5 ft (1.52 m) below the wet deck aft of Station 5.5. This depth allows the vehicle to operate safely in high State 2 seas (2.9 ft; 0.88 m). The overall thickness of the main centerbody is 3 ft, which allows enough volume for flap and ramp mechanisms, fuel storage, and flotation and stability off-cushion. This dimension possibly could be reduced to 2 or 2 1/2 ft (0.61 or 0.76 m), which would allow some decrease in structural weight without fatally compromising the above conditions.

The endplates (sidehulls) were designed using the latest SES technology. The endplate cross sections at several stations are shown in Figure 2. The bow stations (forward 9 ft; 2.74 m) of the endplate have a 20-deg deadrise from the keel outboard. This relatively low deadrise allows large hydrodynamic loads to be generated on the forward endplate in the event of a vehicle pitch down or wave impact, thus improving longitudinal stability. The cross section from Station 9 aft is constant with a 45-deg deadrise

angle. A higher deadrise angle (60 deg) would probably reduce drag, but lateral stability characteristics would be compromised. A good design guide for roll stability is that the force on the endplate (perpendicular to the planing surface) should pass above the craft's center of gravity. A spray rail for drag reduction is located just above the planing surface along the full endplate length.

The propulsor is a hypothetical marine version of the Pratt and Whitney JT9D-7Q having a maximum thrust at sea level of 53,000 lb (235.7 kN). The centerline of the propulsor at the jet exit is located 27 ft (8.2 m) forward of the bow of the landing craft and 12.68 ft (3.86 m) above the endplate keel. The position propulsor was determined using the methods developed by Smithey et al.[1*] The incoming jet thickness was designed to be 5 ft (1.52 m) equal to the clearance between the wet deck and the water.

The initial flap design is a rigid split flap arrangement which spans the vehicle centerbody. Model testing has shown that the flap should have some flexibility to prevent catastrophic failure of the flap and to improve longitudinal motions in high sea conditions.

The estimated weight breakdown for the PARLC is shown in Table 1. The structural weight was estimated by using the barge weights in Reference 2 and adding 20,000 lb (9072 kg) for the engine support boom, 12,000 lb (5443 kg) for the flap and stern ramp, 10,000 lb (4536 kg) for the bow ramp, and 6,000 lb (2722 kg) for miscellaneous structural weights. The propulsor weight is that of a standard JT9D with a small allowance for marine adap-

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[*]A complete listing of references is found on page 17.

tation. Enough fuel is carried onboard for a 2.5-hr round trip, coming back with minimal payload.

TABLE 1 - WEIGHT BREAKDOWN OF THE PARLC

Structural Weight	100,000 lb (45,360 kg)
Propulsor	9,000 lb (4,082 kg)
Fuel	20,000 lb (9,072 kg)
Crew and Miscellaneous	3,000 lb (1,361 kg)
Payload	230,000 lb (104,328 kg)
Vehicle Gross Weight	362,000 lb (164,203 kg)

A major advantage of the PARLC configuration is the relative abundance of usable deck space. The only structures located above the dry deck are the operator control room and the propulsor boom attachment. The lack of deck clutter allows even very low density equipment to be safely carried without difficulty. Figure 3 shows several typical payload arrangements which might be used. All are weight (not space) limited. All payloads could also be loaded and unloaded easily because of the open deck.

Because the overall width of the PARLC is 35 ft (10.67 m) and its minimum vertical clearance is 18 ft (5.49 m), the PARLC can be carried in 32 percent of the Navy's transport ships (e.g., LST's, LSD's, LPD's).[3] During the spring of 1979, DTNSRDC personnel visited three transport ships in Norfolk, Virginia, to discuss possible modes of embarking and disembarking. The PARLC could be brought into or out of a flooded well deck, either on or off of its PAR cushion. The PARLC could not be turned inside the

transport, however, and would therefore have to be brought in or out of the transport by another propulsion system. The PARLC could be winched in stern first or pulled out stern first.

DESCRIPTION OF CARRIAGE MODEL

A general arrangement of the 1/12-scale PARLC carriage model is shown in Figure 4a. Physical characteristics of the model are listed in Table 2. The primary vehicle structure is polyurethane foam covered with fiberglass. Hardwood is used to spread the loads at attachment points for the endplates, flap, trim tabs, fan mounting brackets, and balance attach points.

The forward mounted propulsor is a lightweight, 8-in. diameter, air-powered, tip-driven fan. The fiberglass and magnesium fan is encased in an aerodynamic shroud. The fan is mounted below a "V"-shaped structure made of 1.5-in. aluminum tubes. A 2-in. block gage is installed between the fan and the fan support bracket for direct thrust measurement. The fan is also instrumented with an rpm readout as a backup for thrust measurement (previous calibration of thrust versus rpm).

The stern flap spans the centerbody and is 7 in. (0.18 m) in chord. Construction is 1/4-in. plywood with 1/2-in. square hardwood reinforcing around the perimeter. At $_f$ = 45 deg, the flap extends to the same depth as the endplates.

Trim tabs are located at the stern of both the port and starboard endplates. These 4.2-in. by 4.2-in. plates are set at angles from 0.0 to 20.0 deg. At 0.0 deg, the tabs are flush with the endplate, but at 20.0 deg relative to the planing surface of the endplate, large pitch-down moments can be generated for trim control. By differentially deflecting the trim

TABLE 2 - PHYSICAL CHARACTERISTICS OF A 1/12-SCALE PARLC MODEL

Gross Weight	208.5 lb	(92.72 kg)
Model Dimensions		
Overall Length	90.0 in.	(2.29 m)
Overall Beam	35.0 in.	(0.89 m)
Cushion Dimensions		
Length	90.0 in.	(2.29 m)
Beam	29.0 in.	(0.74 m)
Height	5.0 in.	(0.13 m)
Sidewall Dimensions		
Length	90.0 in.	(2.29 m)
Beam	3.0 in.	(0.076 m)
Height	8.0 in.	(0.023 m)
Water Rudders (2)		
Shape	Square	
Area	4.0 in.^{2}	(25.81 cm^2)
Trim Tabs (2)		
Shape	Square	
Area	17.64 in.^{2}	(113.8 cm^2)
Propulsor Rudder (1)		
Area	12.5 in.^{2}	(80.65 cm^2)
Propulsor Location		
Distance from Bow to Fan Centerline at Exit	31.75 in.	(0.81 m)
Distance from Dry Deck to Fan Centerline at Exit	11.5 in.	(0.29 m)
Reference Length	90.0 in.	(2.29 m)

tabs (e.g., port trim tab 15 deg, starboard trim tab 0.0 deg), yawing moments can be generated for turning. Details of the carriage model trim tabs are shown in Figure 4b.

Primary loads data are taken from a six-component strain gage balance. The balance center was located midway between the bow and stern of the model. The balance was attached above the model in a gimbal which allows free or fixed testing in both pitch and roll. Most testing in calm water was done with the model fixed in pitch and roll while measuring pitch moment. The model was tested free in pitch (pitch moment = 0.0) during the sea condition portion of the test, with the center of gravity located at the balance center.

Pressure data are recorded from eight locations on the craft centerbody: three bow, three stern, and two additional along the centerline equally spaced between the stern and bow locations.

Pitch, yaw, and roll angles were measured with precision one-turn potentiometers.

PERFORMANCE OF CARRIAGE MODEL

Optimum performance over the speed range generally occurs at a pitch angle between 0.5 and 1.0 deg. The data shown in Figure 5 are for a pitch angle of 0.5 deg with flap angles of 12.0, 23.5, 32.5, and 45.0 deg. For the flap angles tested, δ_f = 23.5 deg gives the optimum performance at all speeds. A similar investigation for various fan angles shows that a fan angle of 30 deg is optimum over almost the entire speed range.

Froude scaling the carriage data to obtain full-scale predictions, a top speed of 90 knots (46.3 m/s) in calm water is predicted (Figure 6). In mid State 2 seas ($H_{1/3}$ = 2.2 ft; 0.67 m), the PARLC's top speed drops

off to 84 knots. Figure 6 shows the original full-scale drag estimates using SES drag prediction techniques[4] and Smithey's methods[1] for calculating the drag associated with the PAR phenomenon. The PARLC has a sharp edge at the bow, the flow spilling over the bow remains unattached, and the full value of drag calculated by Smithey's methods is used, rather than one-half of the value as suggested for airfoils.

Also shown in Figure 6 are the installed maximum thrust and normal rated thrust of the JT9D turbo fan. The PARLC would take off and accelerate through hump with the engine operating at maximum thrust (hump margin 30 percent) and, at 40 knots (20.6 m/s), the thrust would be reduced to normal power settings for final acceleration and cruise.

The predicted drag is lower than the scaled model drag at speeds near hump. This higher drag is probably due to increased hydro drag on the flap arrangement of the PARLC. Drag prediction techniques for SES's assume a flexible planing rear seal operating at an angle of about 6 deg, which is near optimum for a planing surface. The PARLC rear flap is rigid and operates at 23.5 deg relative to the undisturbed water level - a much more inefficient condition if the flap is wetted. Ideally, the next PARLC carriage model will have a gaged flap so that its loads can be determined and compared with that of the SES predictions. Another possibility is to test the PARLC with a compliant rear planing seal.

EFFECT OF CENTER OF GRAVITY AND TRIM ON PERFORMANCE

Figure 7 shows drag versus trim angle at model speeds of 30 and 40 ft/sec (9.1 and 12.2 m/s). Minimum drag occurs at trim angles of 1.0 deg (30 ft/sec) and 0.9 deg (40 ft/sec). These data are for the model fixed in pitch; therefore, pitch moment was measured.

Pitch moment versus trim angle for model speeds of 30 and 40 ft/sec (9.0 and 12.2 m/s) are shown in Figure 8. At 30 ft/sec (9.1 m/s), the optimum trim angle is 1.0 deg, and with the cg at 50 percent, the pitch moment is 40 ft lb (5.53 m-kg). The model weight is 208 lb (94.3 kg); the cg should be moved 2.31 in. (5.87 m), or 2.56 percent forward, to trim the model at 1 deg. Similarly, at 40 ft/sec (12.2 m/s) 80 knots full scale, the cg should be located 43.15 in. (1.10 m) aft of the bow for optimum drag conditions. Table 3 lists the forward and aft cg limits necessary to keep the vehicle drag within 5 and 10 percent of the minimum drag conditions.

Another method of controlling vehicle pitch attitude, and therefore drag, is to use the trim tabs collectively. Figure 9 shows the change in pitch moment (from baseline trim tab angles equal zero) versus the incremental drag associated with trim tab deflection for various speeds. Using the trim tabs to generate pitch moment, the vehicle can operate at its optimum trim angle [= 0.9 deg at 40 ft/sec (12.2 m/s)] with the drag penalty associated with the trim tab deflectors. The limits of cg travel possible, while still keeping the PARLC within 5 or 10 percent of minimum, are also shown in Table 3.

The final method of controlling pitch attitude and trim drag is with a variable fan angle. Changing the propulsor angle gives direct pitch moment control, but if the angle is set at some point other than 30 deg (optimum), the loss in PAR efficiency will result in a drag penalty. Figure 10 shows the drag increment associated with incremental pitch moment, and the results in terms of possible cg ranges are shown in Table 3.

TABLE 3 - FULL SCALE CG RANGES FOR DRAG $\leq$ 1.05 D_{min}

AND DRAG $\leq$ 1.10 D_{min}

		Free to Pitch (%)	Trim Tabs (%)	Fan Angle (%)
D $\leq$ 1.05 D_{min}	cg Fwd limit	46.9	47.0	46.7
	cg Aft limit	48.7	48.9	49.2
D $\leq$ 1.10 D_{min}	cg Fwd limit	46.8	46.0	45.4
	cg Aft limit	49.0	49.9	50.5

In summary, the largest latitude in possible cg location is available when vehicle trim angle is controlled by fan angle. For minimum drag operation, the cg position could range from 45.4 to 50.5 percent of the craft length aft of the bow.

PITCH STIFFNESS

Figure 11 summarizes the effect of speed on pitch stiffness for the PARLC at its design gross weight of 208.5 lb (94.58 kg); the fan was at 30 deg. At all trim angles investigated, the model was stable in pitch for all speeds. The relative degree of pitch stiffness is a function of the

slope of the line through the data. By dividing the slope by the model's overall length and weight to account for scale, this pitch stiffness can be compared to other high-speed surface craft. The PARLC has a pitch stiffness of 0.019/deg, and the SES-100A1 has a pitch stiffness of 0.018/deg.[5] Probably, the forward mounted propulsor on the PARLC stiffens the vehicle's pitch response as much as the bow seal does on the SES-100A1.

TURNING DEVICES

The potential performance of three devices for turning the PARLC was evaluated during this investigation. The first device, a small rudder positioned in the slip stream of the fan, is shown in Figure 12. The maximum angle to which the rudder can deflect the fan exhaust is 15 deg. The second device, the water rudder mounted to the transom, is shown in Figure 4. The rudder was tested up to 20 deg. Deflecting the trim tabs differentially was also evaluated as a potential turning device. A maximum differential deflection of 15 deg was evaluated.

The incremental change in drag versus yaw moment and the regions of performance for the various turning devices are shown in Figure 13. The regions include performance at all model speeds from 0 to 40 ft/sec (0 to 12.2 m/s), with the high deflection angles along the upper boundaries.

Some combinations of differential trim tabs and thrust deflection can be used to maneuver the craft, although some problems exist with these combinations. For example, when using the differential trim tabs, the vehicle turns about the most deflected tab (also the tab with the most lift), and therefore tends to roll out of the turn.

The vehicle's general lack of a stability fin can also cause lateral stability problems. To date, no SES craft has been built without some

kind of stability surface below the water surface near the stern of the craft. Another way of providing good lateral stability characteristics would be to operate the craft at fairly high pitch angles (3 deg and up). Operating at these high attitudes also gives the craft excellent pitch stiffness. Unfortunately, operating at high pitch angles results in some degradation in performance (Figure 14). A change in pitch angle from 0.5 to 2.0 deg results in a 25-percent increase in drag at 40 ft/sec (12.2 m/s).

Based upon the potential lateral stability problem and the poor performance at high pitch angle, some sort of stability fin should be considered. This fin should be a rudder, which would give excellent turning performance at most speeds.

MOTIONS

The 1/12-scale carriage model of the PARLC was tested in scaled significant waves up to 4.0 ft (1.22 m) in mid State 3 seas, although the craft was originally designed for only State 2 seas. Motions were severe in 4-ft seas with some bow slamming. By increasing the endplate depth and increasing the flexibility of the rear flap, the PARLC could operate in mid State 3 seas.

Performance in 2.2 ft (0.67 m) significant seas (mid State 2 seas) actually suffers very little; cruise speed is reduced from 90 knots (46.3 m/s) to 84 knots (43.2 m/s). Overall, the vehicle motions are well within the habitability limits of Reference 6. Two of the habitability limits are shown in Figure 15. The first limit, labeled long-term tolerable, represents conditions which should not cause motion sickness in most people. This limit is the most severe in the region of concern (full-scale encounter

frequencies between 1 and 4). The data shown represents the full range of speeds investigated and the accelerometer locations. Note that all of the PARLC data recorded falls within the criteria for long-term tolerable motions. The second condition--10 percent motion sickness in less than two hours -- represents an even more severe condition. The PARLC does not appear to have any limits due to motion sickness.

REMOTELY PILOTED FREE FLIGHT MODEL

A 1/20-scale free flying model of the PARLC was flown several times during 1979. The first test was conducted at the Quantico Marine Base to determine the vehicle characterisitcs while operating in open water at various headings to the wind and sea, and the relative operator skill level required to fly the craft.* The second test was conducted at a small beach on a tributary of the Chesapeake Bay to study possible beaching techniques.** The final test series was conducted at DTNSRDC, Carderock, in a small pond to investigate cg limits on performance and stability.***

Significant results of these tests include:

1. The R/C model successfully operated in seaway conditions to mid State 5 seas.

2. Differential trim tabs were limited in effectiveness for turning.

3. Several air rudder designs were effective for maneuvering.

4. The water rudders were, by far, the most effective method for turning.

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*Reported informally by Earl McCabe (1603:EFM:gsd memo, 12 Jul 1979).
**Reported informally by Earl McCabe (1603:EFM:cam memo, 14 Dec 1979).
***Reported informally by Bert Ellis (1603:BKE:cam memo, 17 Dec 1979).

5. The R/C model was flown onto and off of the beach at its maximum weight (for the installed thrust).

6. The capability of the craft to come up on the PAR cushion for a given thrust is a function of the cg position and gross weight. In general, the higher the gross weight, the farther aft the cg must be located to allow takeoff.

7. No major stability problems associated with vertical cg locations were experienced during the testing.

SUMMARY

Results of the first PARLC studies are:

1. Minimum drag occurs with the vehicle operating at trim angles between 0.8 and 1.0 deg.

2. Using the propulsor angle for trim control (to give minimum drag), the PARLC can operate with its cg located from 40.85 to 45.45 ft (45.4 to 50.5 percent) aft of the bow.

3. The pitch stiffness of the PARLC is similar to current SES designs, with the forward mounted propulsor having the same effect on pitch stiffness as would the bow seal on an SES.

4. A small water rudder would give excellent turning performance at most speeds, and probably increase the lateral stability of the PARLC considerably.

5. Vertical accelerations of the PARLC in simulated State 2 seas were well within the accepted habitability limits.

6. The PARLC can operate successfully in various sea conditions and headings to the sea.

7. Transit onto and off of the beach was demonstrated using the PARLC free flight model.

CONCLUSIONS AND RECOMMENDATIONS

The investigations, carriage tests, and free flight model tests have shown the PARLC to be a viable, attractive surface mobility concept. The PARLC is capable of transiting the distance from ship to shore at speeds in excess of 90 knots, while carrying payloads in excess of 200,000 lb (90,720 kg). Cargo can be offloaded on the beach or just outside the surf zone, depending on the cargo, beach conditions, time requirements, and other factors. The concept, however, also has its critical technology issues. First among these issues is the adaptation of an aircraft turbo fan engine, such as the JT9D, for operation in the marine environment. Another critical issue is the vulnerability of the stern flap to wave impacts. (Should the flap be soft and compliant, or rigid? How can the apparent loads on this flap at speeds near hump conditions be reduced?)

The following are recommendations for follow-on technology development of the PARLC concept:

- Using data generated during the first PARLC test, SES drag prediction techniques, and PAR theory, conduct a parametric sizing study to determine the performance of a family of PARLC designs.
- Consider installing 5 to 10 percent more thrust than required so that the PARLC can operate at full speed over a wider range of cg positions.
- Begin a preliminary study of possible solutions to the salt water and engine marine adaptation problem.

- Experimentally investigate one or more types of "soft" flap arrangements. The "soft" flap should reduce vehicle motions in waves, decrease the vulnerability of the flap to water impact, and possibly decrease drag.
- Improve drag prediction techniques for the PARLC by instrumenting the flap on the 1/12-scale carriage model so that flap drag can be measured separately.
- Conduct lateral stability carriage tests and dynamic analysis of the PARLC lateral stability characteristics. (Mounting the propulsor well ahead of the basic hydrodynamic vehicle may have a significant effect on lateral stability, which does not show in the SES data.)
- Conduct further experimental investigations to study pitch stiffness at low and negative trim angles.
- Test one other model of a different length-to-beam ratio to establish prediction techniques used for future parametric analysis.

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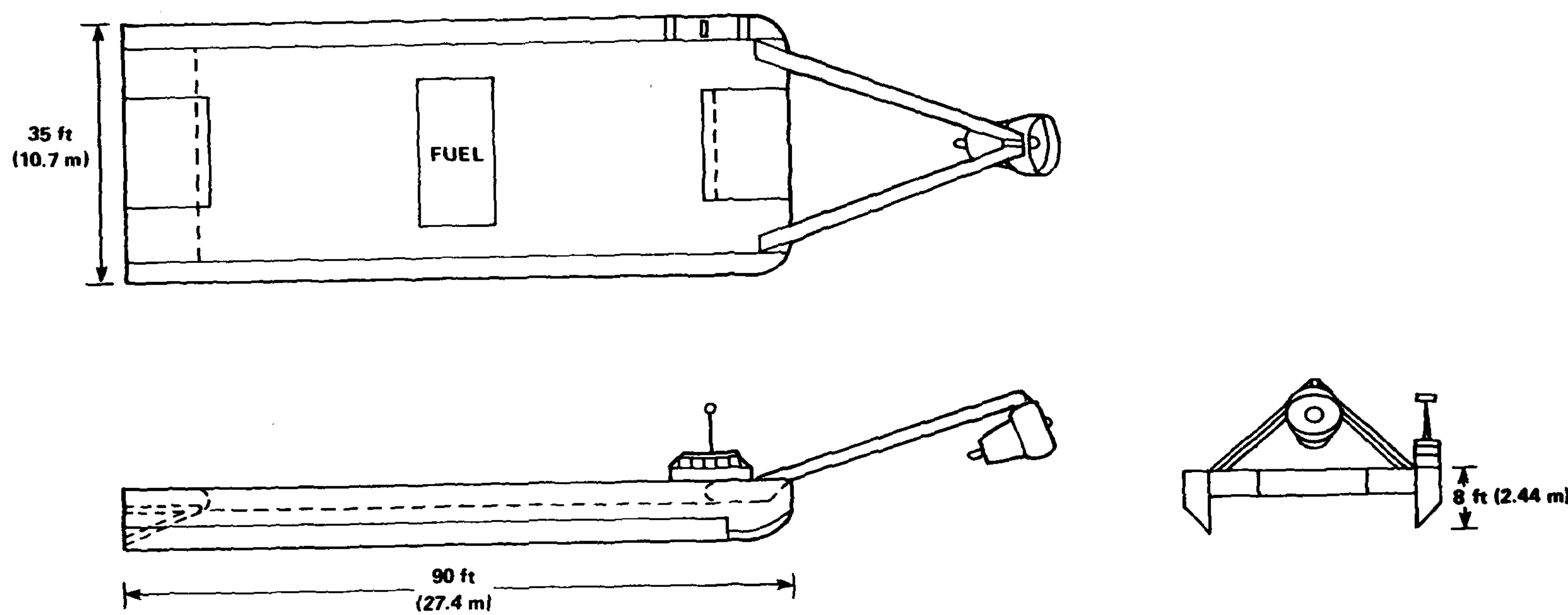


Figure 1 - Three-View of the PARLC

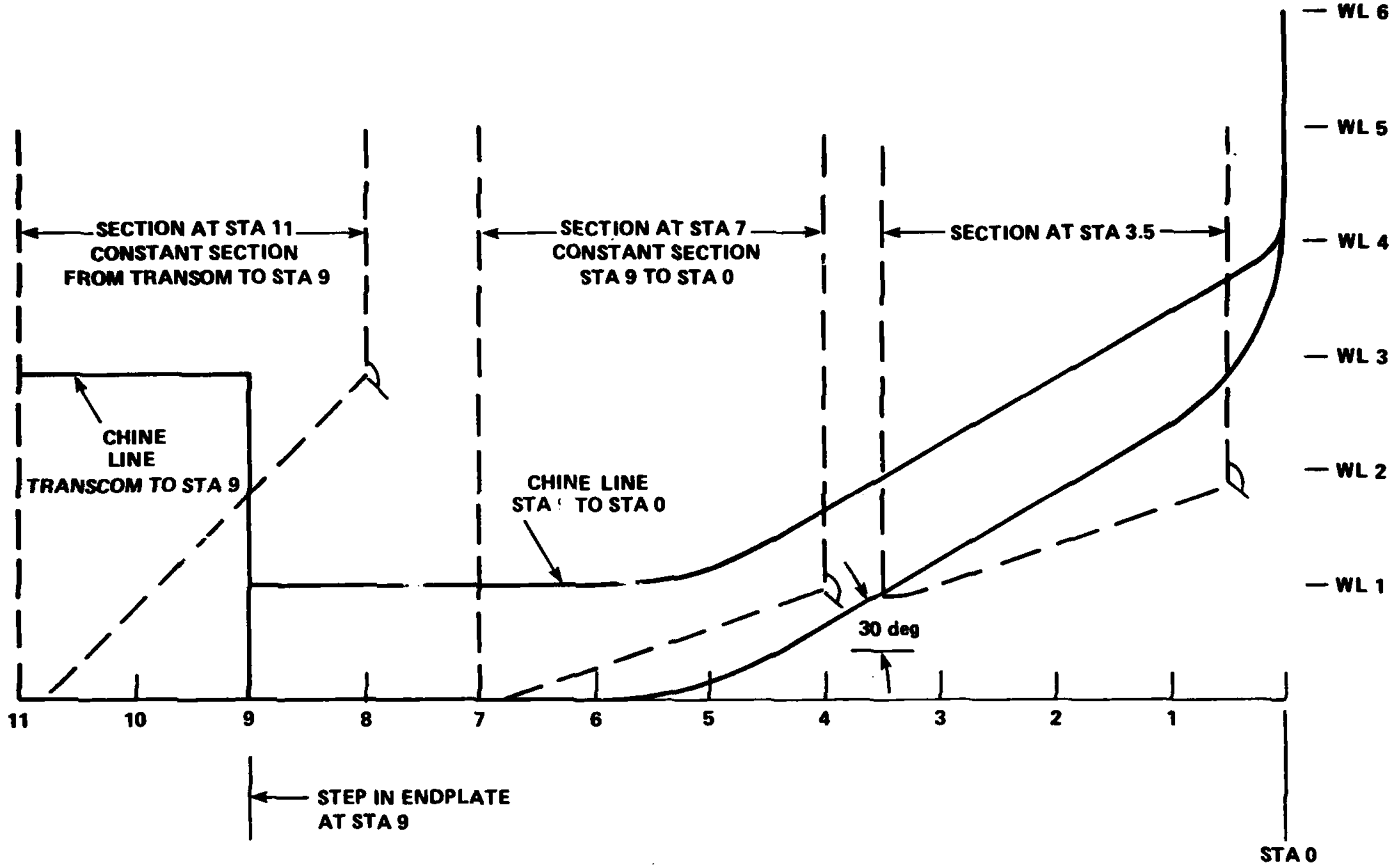


Figure 2 - Endplate Details

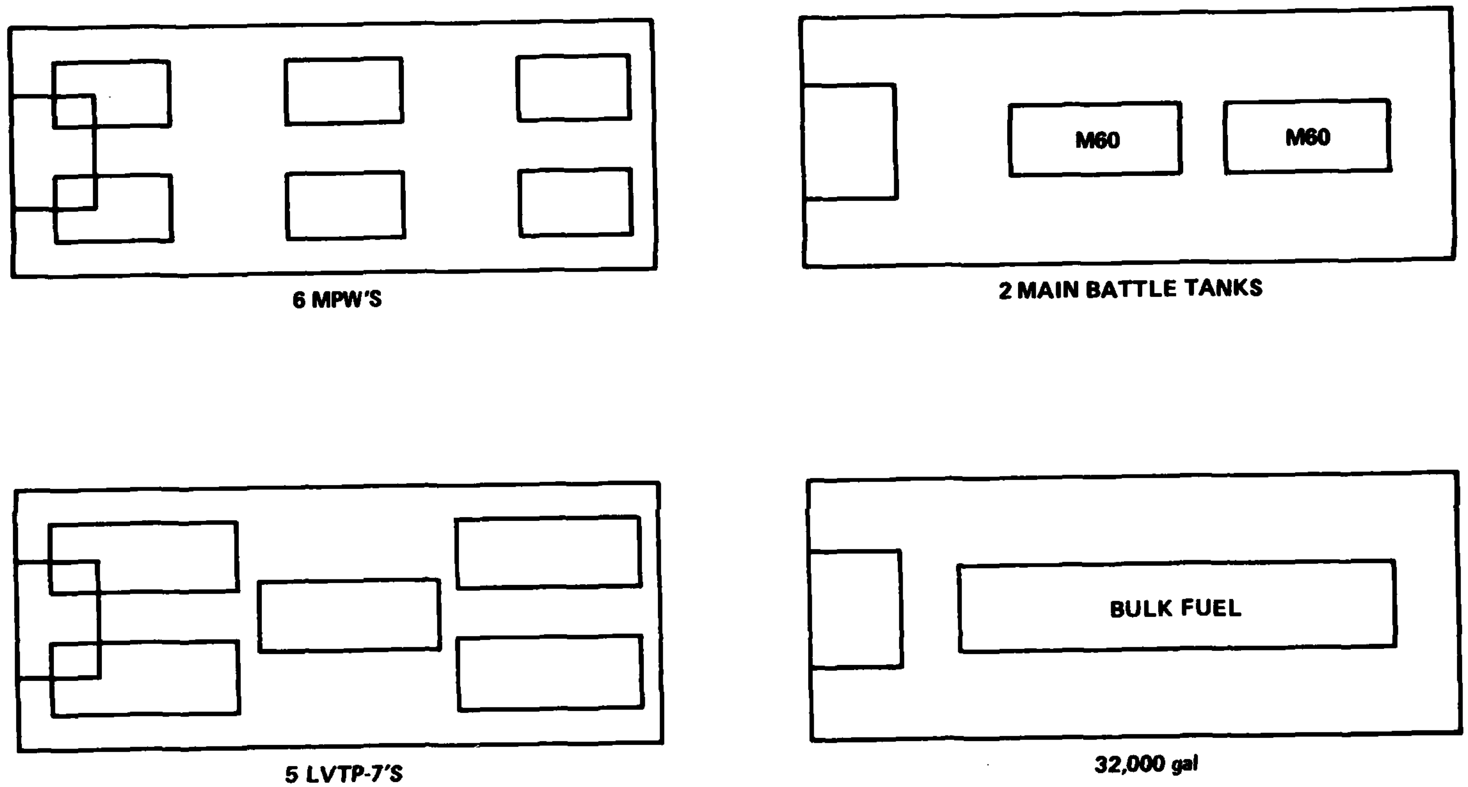
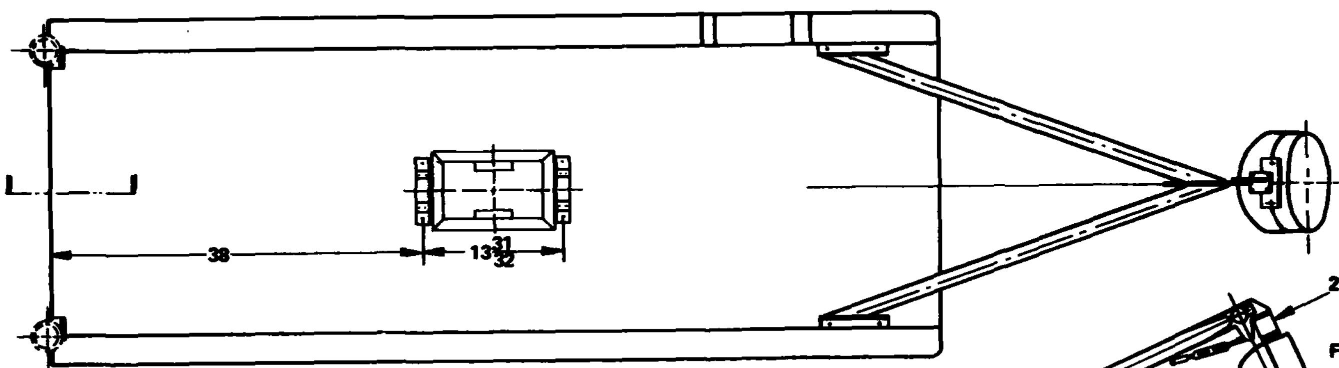


Figure 3 - Typical Payload Arrangements

Figure 4 - PARLC Carriage Model



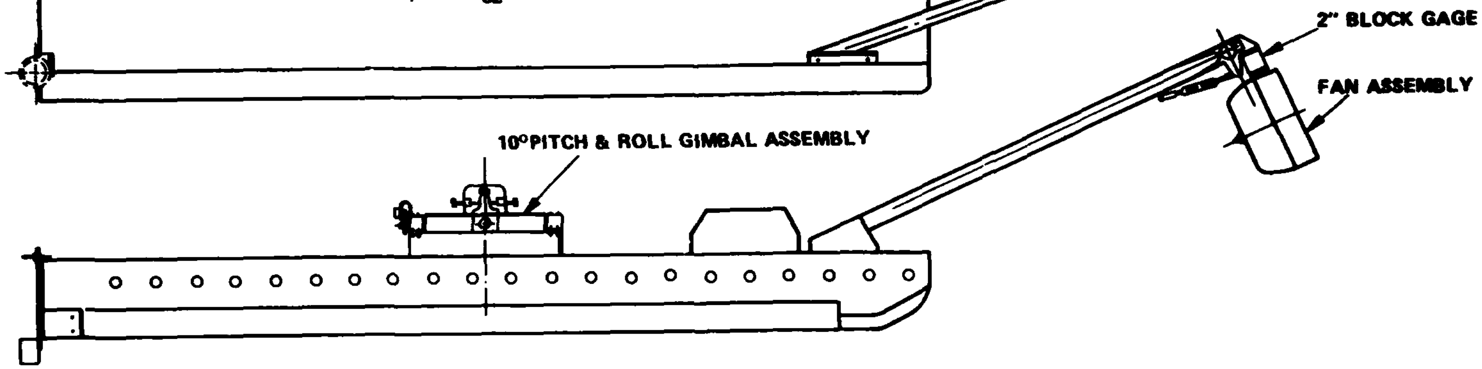
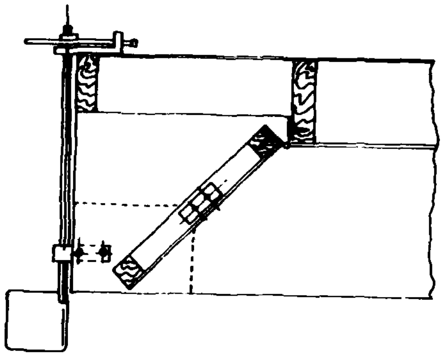
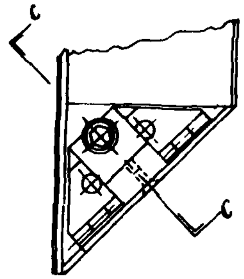


Figure 4a - General Arrangement

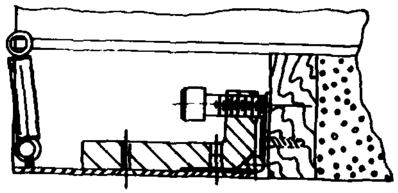
Figure 4 (Continued)



SECTION A-A
FLAP AND WATER RUDDER



SECTION B-B
TRIM TAB



SECTION C-C
TRIM TAB

Figure 4b - Details

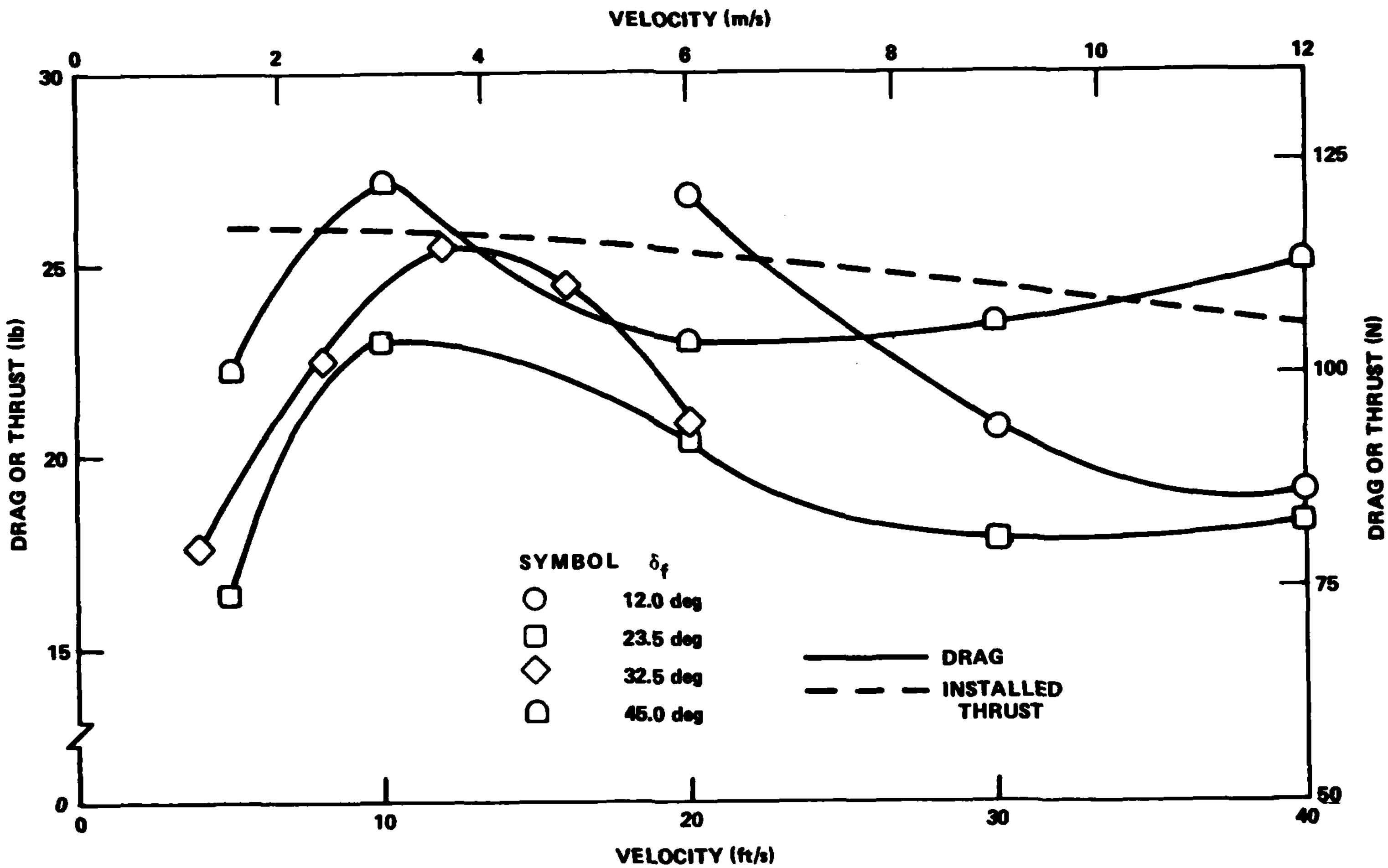


Figure 5 - Effect of Flap Angle on Performance

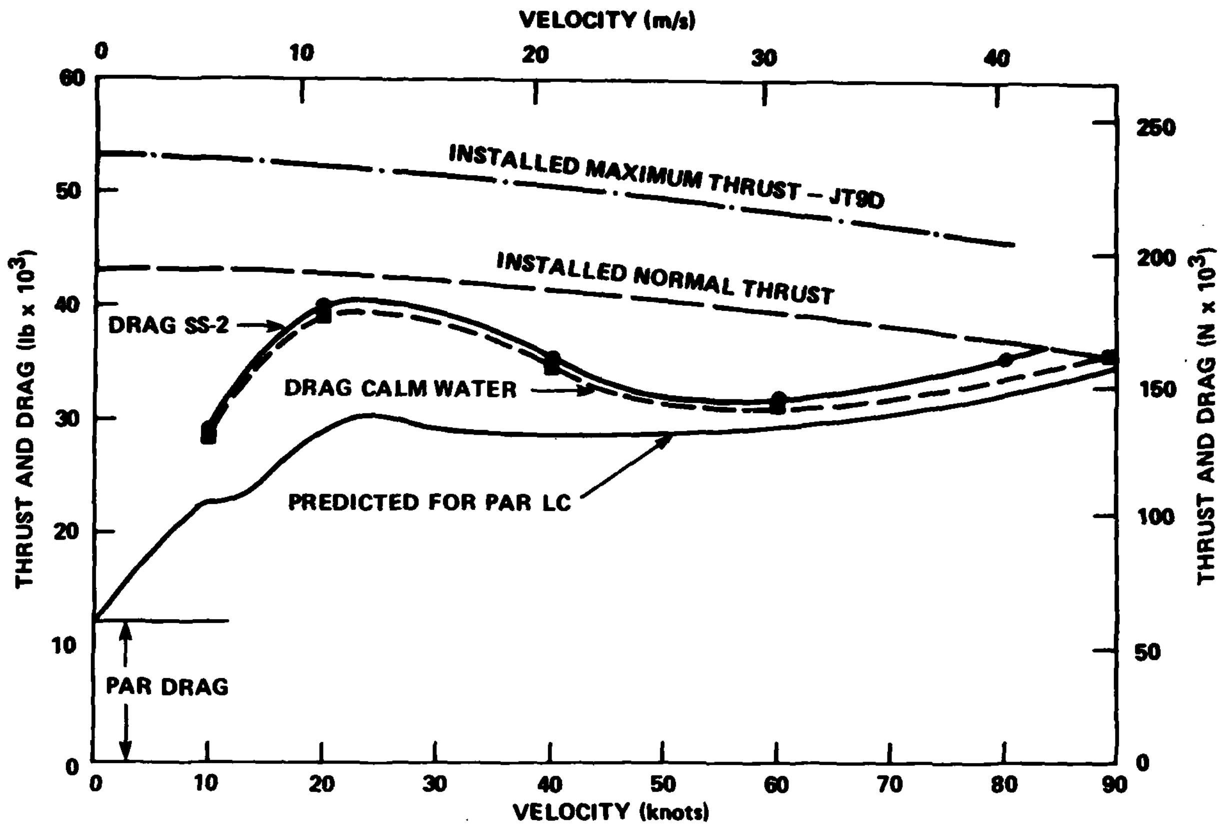


Figure 6 - Full-Scale PARLC Performance

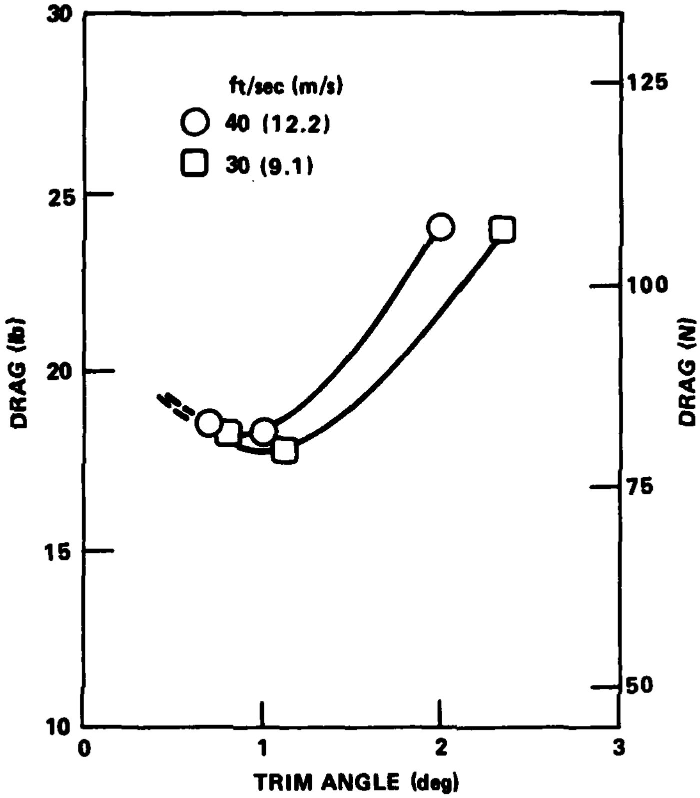


Figure 7 - Effect of Trim Angle on Performance

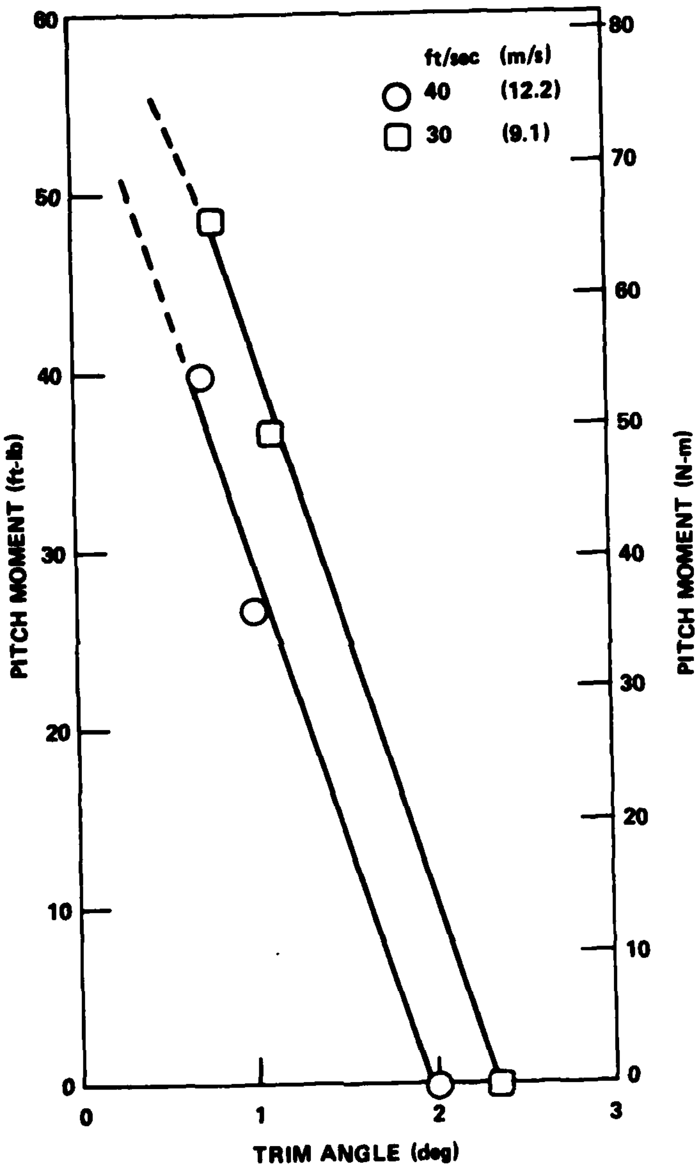


Figure 8 - Pitch Moment Versus Trim Angle

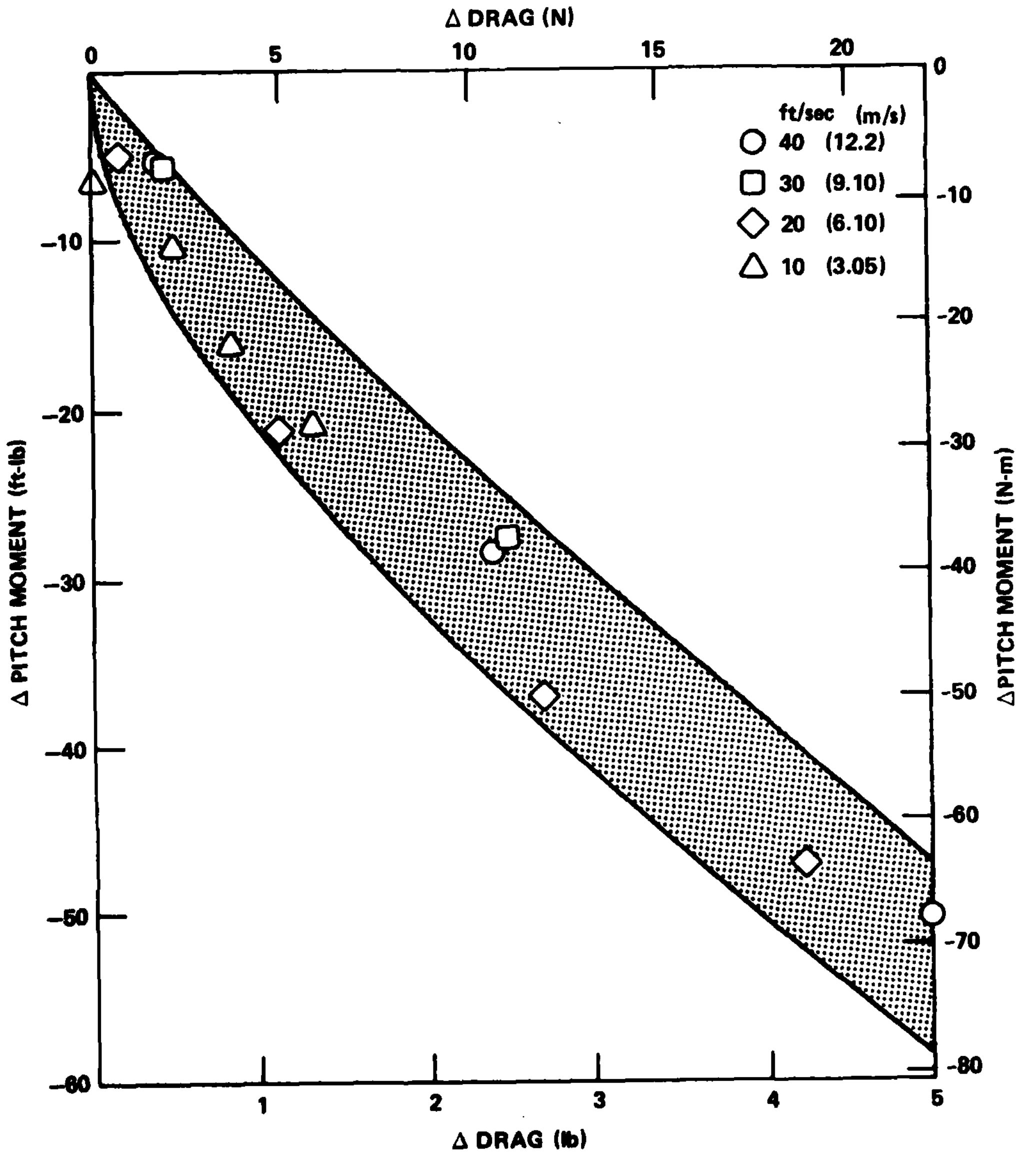


Figure 9 - Effect of Trim Tabs for Pitch Control

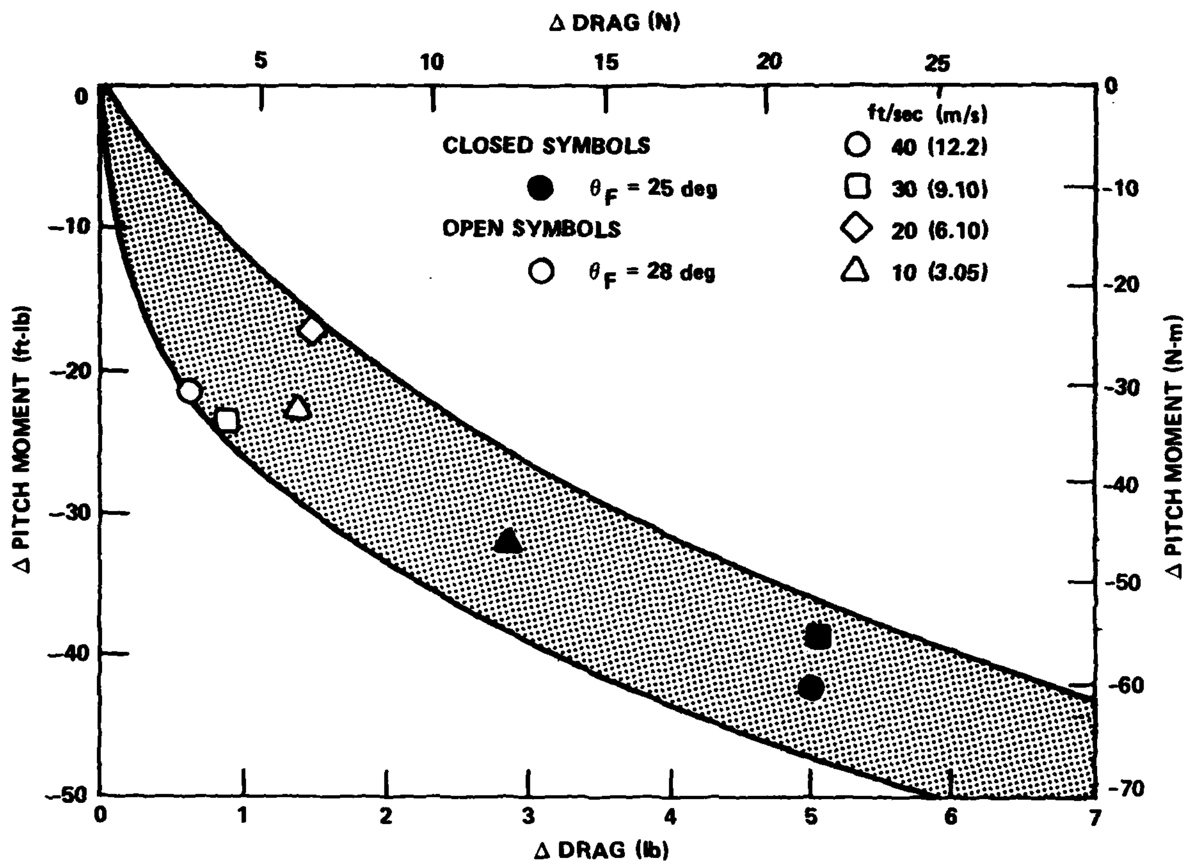


Figure 10 - Effect of Fan Angle for Pitch Control

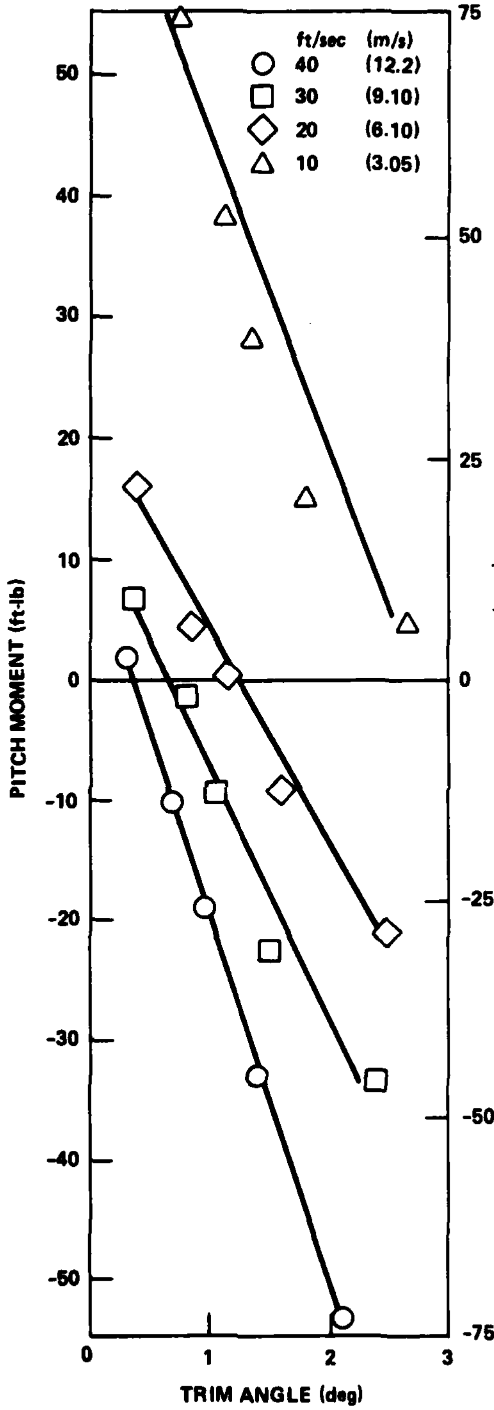


Figure 11 - Pitch Stiffness of the PARLC

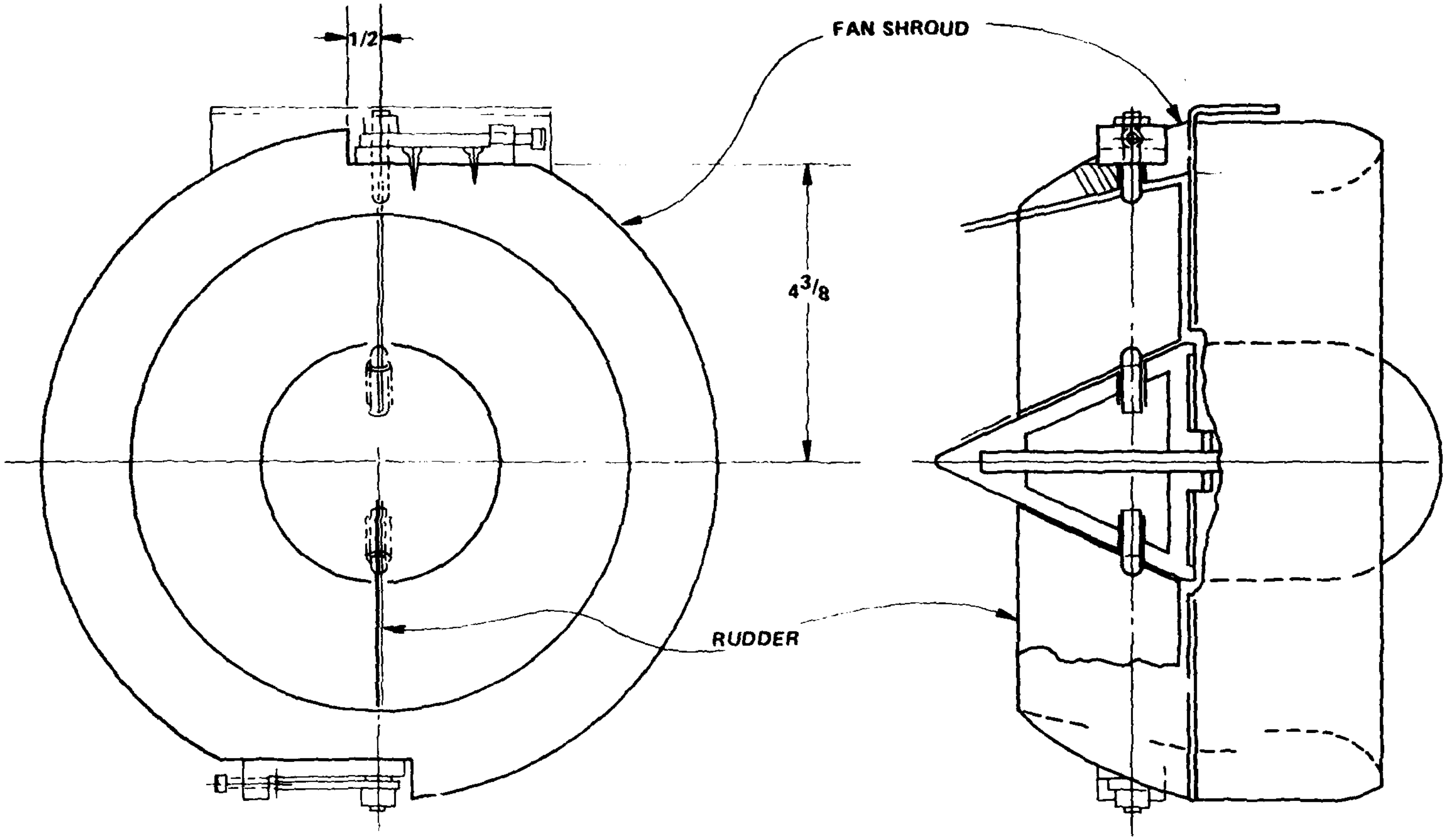


Figure 12 - Fan Arrangement with Thrust Vectoring Rudder

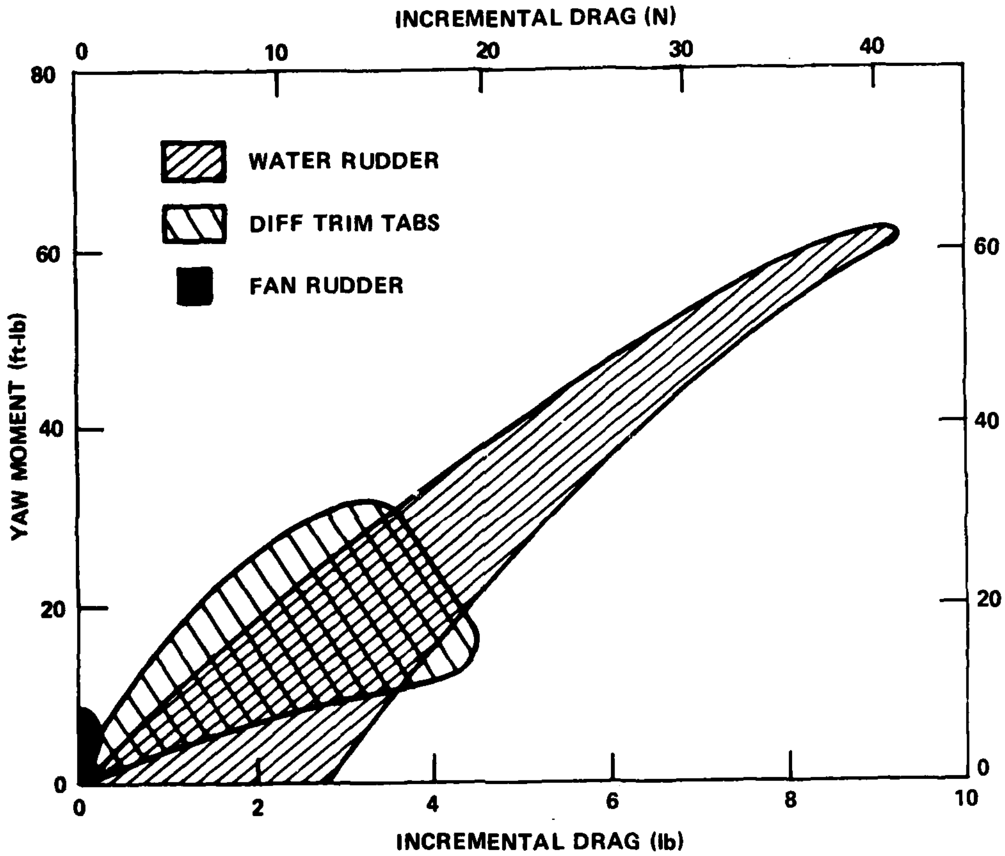


Figure 13 - Effect of Various Turning Devices

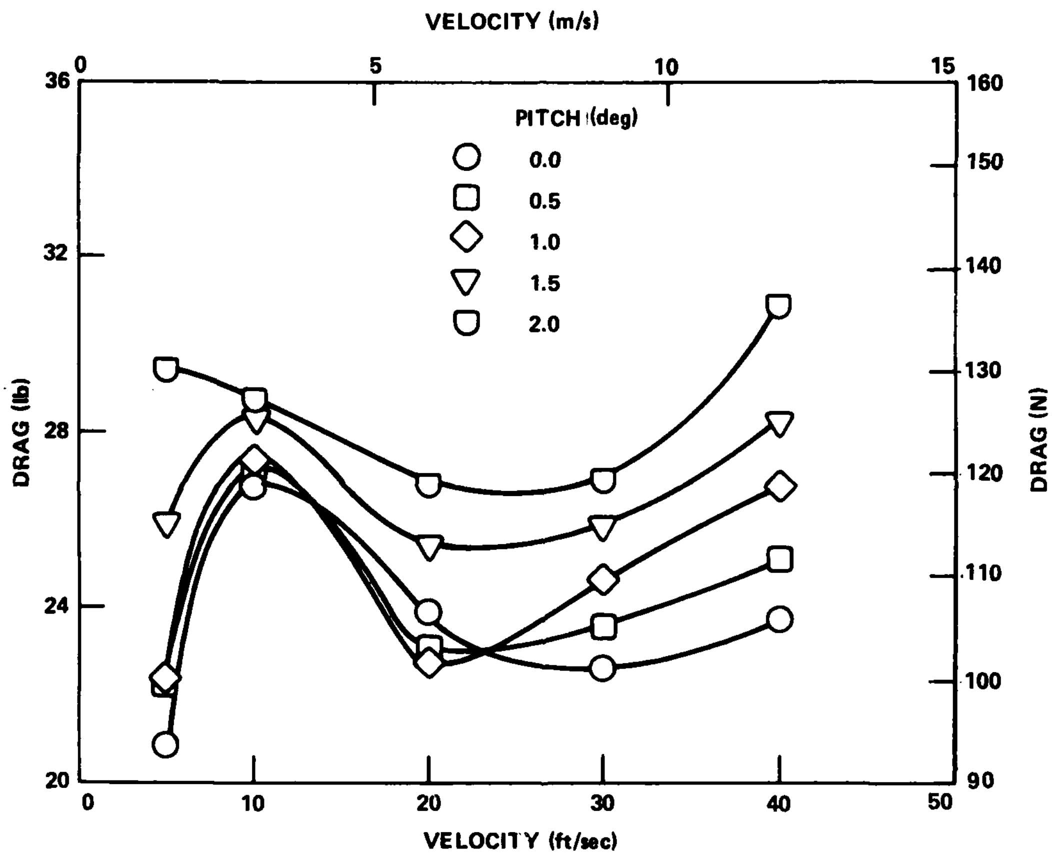


Figure 14 - PARLC Performance at Various Pitch Angles

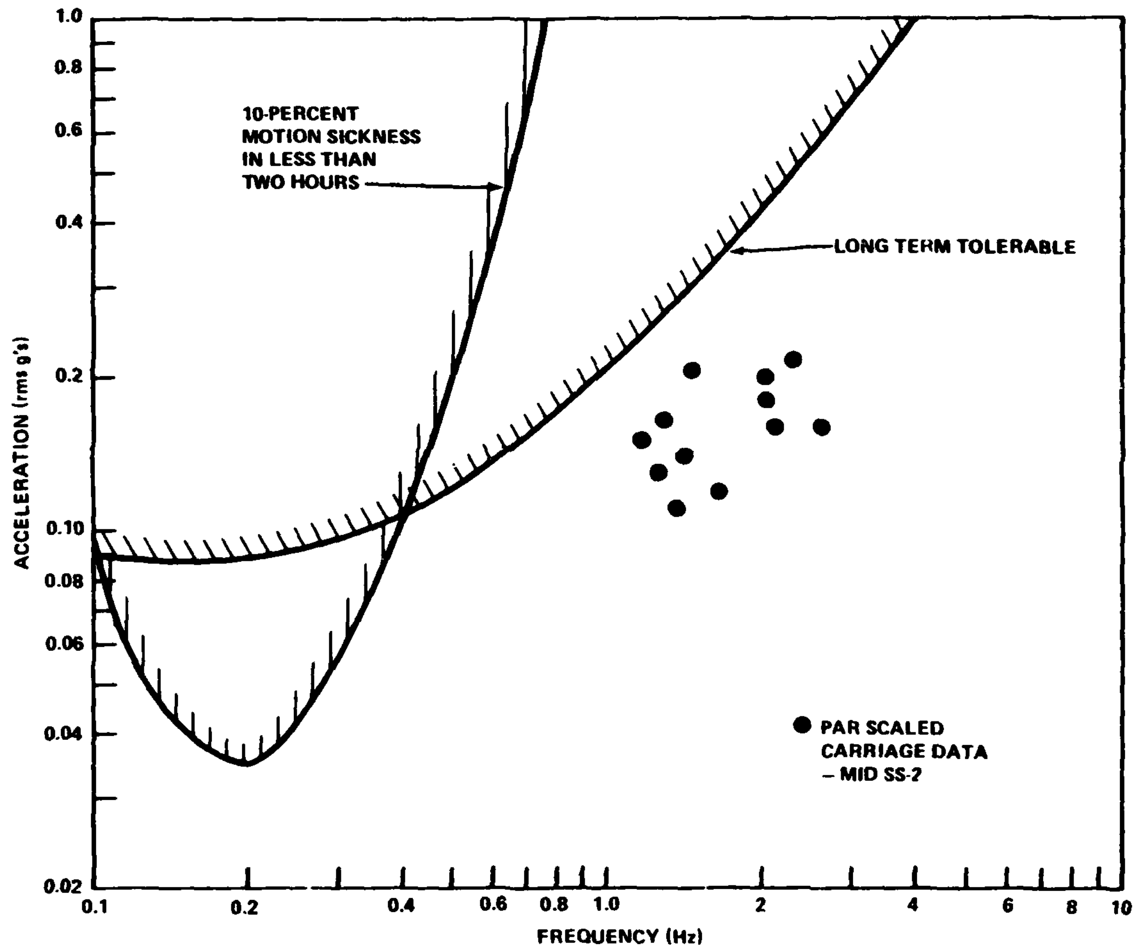


Figure 15 - PARLC Ride Quality in Cruise

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